Human Brain Project

Anastasia Brovkin[1] Rene Werner[1] Julia Michel[1] Alexandros Goulas[1] Timo Dickscheid[2] Katrin Amunts[2, 3] Petra Ritter[4, 5] Claus C. Hilgetag[1, 6]

Enriching the human connectome:

BigBrain & The Virtual Brain to feature the newly digitized Economo & Koskinas human cytoarchitectonic atlas

1 Department of Computational Neuroscience, University Medical Center Hamburg-Eppendorf, Martinistr 52, Hamburg,, Germany
2 C. and O. Vogt-Institute for Brain Research, University Hospital Düsseldorf, Düsseldorf, Germany
3 Institute of Neuroscience and Medicine (INM-1), Research Centre Jülich, 52425 Jülich, Germany
4 Brain Simulation Section, Department of Neurology Charité Universitätsmedizin Berlin & Berlin Institute of Health, Berlin, Germany
5 Bernstein Center for Computational Neuroscience Berlin, BCCN, Berlin, Germany
6 Department of Health Sciences, Boston University, 635 Commonwealth Avenue, Boston, USA

Background

- Fundamental relations between architecture, connectivity and function of the cerebral cortex still remain elusive. This is partly due to a lack of detailed, quantitative cytoarchitectonic data for the human brain
- Currently, the only comprehensive source of such information is the classic work of von Economo and Koskinas [1,2] – which, however, is only available in a paper-based 2D atlas in non-standard space
- Our project aims to construct a virtual 3D model of the von Economo and Koskinas atlas in stereotactic space

From plaster model to virtual 3D model

- **Starting point:** Plaster models from the von Economo era
- Recent studies [3-5] manually mapped the von Economo and Koskinas parcellation onto the FreeSurfer Desikan-Killiany atlas [6] based on the textual description and 2D drawings in [1,2,7]

- To circumvent previous limitations, we aim to explicitly define a virtual 3D von Economo and Koskinas model independent of existing reference geometries – this is made possible with the use of two individual, well-preserved copies of the 3D plaster model of the cortical parcellation [1,2] manufactured in the 1920s for illustrative use in medical training - ordered, authenticated and praised for their accuracy by von Economo himself

Constantin von Economo
Professor of Neurology and Psychiatry at the University of Vienna, Austria

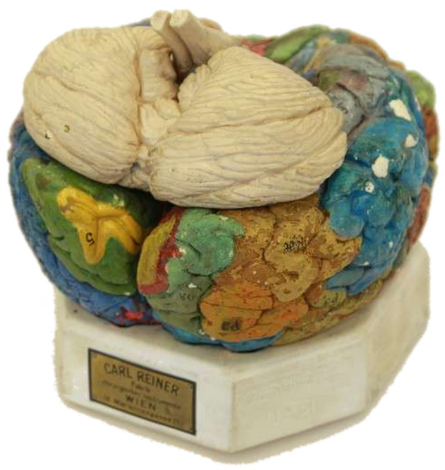
Cellular Structure of the Human Cerebral Cortex

Translated and edited by

Lazaros C. Triarhou
Professor of Neuroscience and Chairman of Educational Policy, University of Macedonia, Thessaloniki, Greece

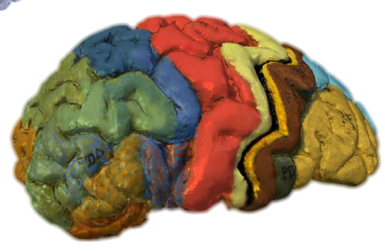
Fig. 62. A patented plaster model of the human brain, with the various cytoarchitectonic areas marked according to the original Economo and Koskinas (1925, 2008) lettering system, and indicated by Economo with various colors on the convexity and median facies of the cerebral hemispheres, was manufactured in the 1920s by Fabrikation Chirurgischer Instrumente Carl Reiner, Mariannengasse 17, Wien IX (still operating today in the same locality after four generations). Economo made a demonstration using such a model in his December 3, 1929 lecture at the Section on Neurology of the New York Academy of Medicine (Economo, 1930f, g). One additional model is on display at the *Institut für Geschichte der Medizin* (Institute for the History of Medicine) of the University of Vienna, next to Economo's death mask. The numbers in the upper left frame (mid-sagittal hemispheric view) denote the five structural types of isocortex (cf. fig. 8 and 9 in the introductory chapter). Photos courtesy of Nikolaus Reiner, Manufaktur Chirurgischer Instrumente Carl Reiner GmbH. Vienna. Austria.

Step 1:
3D scanning of individual parts of the plaster model

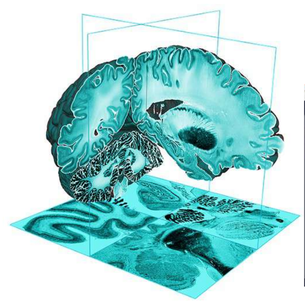


Step 2:
Reconstruction and composition of individual scans

Step 3:
Verification and correction of geometry



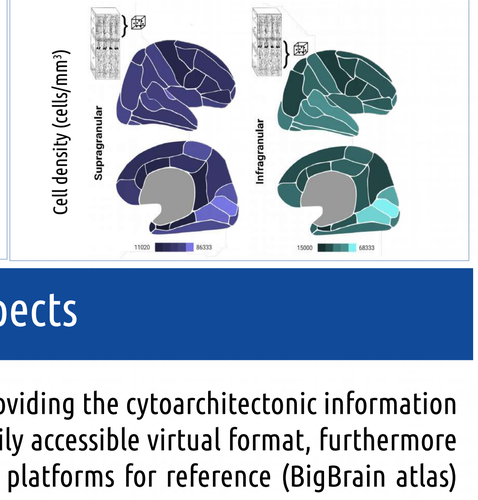
Step 4:
Correction of damaged plaster model coloring and delineation of cortex regions



Step 5:
Registration to standard space i.e. MNI 152, BigBrain

Table 6. Summative table of quantitative data in sixteen fundamental areas of the frontal lobe. Overall layer thickness based on the present work. Separate dome and wall data and some additional values supplemented from Tables I, III, V and VI in Economo and Koskinas [1925, pp. 794–801].

Area symbol	Area name	Cortical layer	Layer thickness at dome mm	Layer thickness at wall mm	Layer thickness overall mm	Cell content cells/mm³	Cell size, µm* $H_{(min-max)}$/ $W_{(min-max)}$
F_A	precentral area	I	0.18	0.20	0.18	7,000	5/6
		III(II)	1.47	1.40	1.43	55,000	8/7
		IIIa				30,000	12/10
		IIIb				20,000	20/15
		IIIc				15,000	30–60/20
		III(IV)				13,500	20/10
		V	0.80	0.70	0.85	16,000	20–30/20 6–120/30–60
		VIa	1.00	0.70	1.25	25,000	30/15
		VIb	0.70	0.40		15,000	15/10
$F_{A\beta}$	agranular frontal area	I	0.22	0.27	0.22	7,000	4/8
		III(II)	1.40	0.16	1.50	65,000	7/8
		IIIa				30,000	17/12
		IIIb		1.20		25,000	30/15
		IIIc				18,000	35–80/20–30
		III(IV)		0.03		30,000	
		V	0.50	0.47	0.50	25,000	30–40/20–25
		VIa	0.90	0.33	1.37	24,000	30/15
		VIb	0.60	0.37		15,000	15/10
F_C	intermediate frontal area	I	0.26	0.38	0.25	5,000	4/8
		II	0.12	0.17	0.15	55,000	7/5
		IIIa	1.00	0.90	1.00	24,000	15–20/8–12
		IIIb				17,000	25–30/10–12
		IIIc				28,000	30–50/10–20
		IV	0.20	0.25	0.15	45,000	10–15/9
		Va	0.46	0.43	0.50	30,000	20–25/10–20
		Vb				15,000	30–40/20
		VIa	0.70	0.50	0.25	20,000	30/15
		VIb	0.45	0.30		12,000	15/10
$F_{C\beta_m}$	magnocellular agranular intermediate frontal (Broca's) area	I	0.21	0.27	0.24	5,000	4/8
		II	0.18	0.18	0.18	55,000	10–15/6–8
		IIIa	1.00	1.00	1.00	28,000	15–20/8–12
		IIIb				26,000	25–30/10–30
		IIIc				20,000	30–60/20–25
		IV	0.16	0.18	0.17	60,000	6–15/4–10
		Va	0.46	0.40	0.43	32,000	20–25/10–20
		Vb				16,000	25–45/15–20
		VIa	0.70	0.55	0.95	20,000	20–30/10–15
		VIb	0.40	0.25		12,500	20/10
F_D	granular frontal area	I	0.21	0.23	0.20	9,000	4–6/8–10
		II	0.18	0.20	0.19	75,000	5–15/4–12
		IIIa	0.78	0.89	0.80	32,000	15–20/7–10
		IIIb				16,000	15–40/7–20
		IV	0.21	0.26	0.24	85,000	6–10/5–10
		Va_1	0.45	0.35	0.45	35,000	15–20/15–20
		Va_2				20,000	20–30/15–25
		Vb				12,000	20–40/20
		VIa	0.52	0.33	0.90	35,000	15–30/10–15
		VIb	0.35	0.20		15,000	15–20/10
$F_{D\Delta}$	middle granular frontal area	I	0.25	0.27	0.26	9,000	4–6/8–10
		II	0.18	0.22	0.20	65,000	6–7/4–6 10–15/6–8
		IIIa	0.82	0.80	0.81	32,500	15–20/7–10
		IIIb					20–30/10–15
		IV	0.24	0.27	0.25	75,000	6–8/5–8
		V	0.40	0.30	0.35	30,000	20/10–15
		VIa	0.45	0.35	0.78	37,000	20/10
		VIb	0.36	0.30		20,000	20/10
$F_{D\Gamma}$	triangular granular frontal area	I	0.18	0.25	0.21	8,000	4–6/8–10
		II	0.12	0.16	0.14	65,000	6–7/4–6
		IIIa	0.78	1.05	0.91	25,000	10–15/10
		IIIb/c				25,000	20–60/15–40
		IV	0.21	0.24	0.22	70,000	6–8/5–8
		Va	0.38	0.40	0.39	30,000	15–30/15–25
		Vb				12,000	20/20
		VIa	0.50	0.36	0.70	37,500	20/8–10
		VIb	0.34	0.50		18,000	15/8–10



A virtual model in standard space

For improved usability, the model will be aligned to standard space i.e. MNI-152

- Comprehensive cytoarchitectonic information [1,2,7] – see figure above –
- will be assigned to the corresponding labels in 3D space
- The resulting digital atlas will be a result of manual verification using two copies of the plaster model, allowing for a more reliable reconstruction and error estimation both in geometry and texture

Applications and prospects

- The digital 3D atlas represents a multiparametric atlas, providing the cytoarchitectonic information of the classic work of von Economo and Koskinas in an easily accessible virtual format, furthermore allowing for its future integration with neuroinformatics platforms for reference (BigBrain atlas) and simulation (The Virtual Brain)
- It offers the prospect of reliably mapping human cytoarchitectonic information [1,2] into common cortical parcellation schemes – supporting new insights into fundamental relations between structure, connectivity and function of the human brain

Acknowledgments
We are deeply grateful to the following contributors for providing us with the opportunity to scan the von Economo plaster models in their ownership:
N. Reiner (of the Manufaktur Chirurgischer Instrumente Carl Reiner GmbH, Vienna, Austria)
The Josephinum, Collections of the Medical University of Vienna, Austria

We are equally grateful to Prof. Lazaros C. Triarhou, of the University of Macedonia, Greece, for his insightful comments and helpful and open correspondence.

References

[1] von Economo, CF, Koskinas, GN (1925). Die Cytoarchitektur der Hirnrinde des erwachsenen Menschen. Berlin: Springer.
[2] von Economo, CF (1927). Zellaufbau der Grosshirnrinde des Menschen. Berlin: Springer.
[3] Scholtens, LH, de Reus, MA, van den Heuvel, M (2015), 'Linking contemporary high resolution magnetic resonance imaging to the Von Economo legacy', Human Brain Mapping 36:3038-46.
[4] van den Heuvel, M et al. (2015), 'Bridging cytoarchitectonics and connectomis in human cerebral cortex', The Journal of Neuroscience 35: 13943-8.
[5] Goulas, A et al. (2016) 'Cytoarchitectonic similarity as wiring principle of the human connectome', OHBM 2016 Annual Meeting.
[6] Fischl, B et al. (2004), 'Automatically parcellating the human cerebral cortex.' Cerebral Cortex 14: 11-22.
[7] von Economo, CF (2009), 'Cellular structure of the human cerebral cortex', Karger.

e-mail: a.brovkin@uke.de
phone +49 (0) 40 7410 - 52111

@Sc1naps

THEVIRTUALBRAIN.

UKE HAMBURG

Department of Computational Neuroscience

Co-funded by the European Union

This project/research has received funding from the European Union's Horizon 2020 Framework Programme for Research and Innovation under the Specific Grant Agreement No. 785907 (Human Brain Project SGA2).